

# Multigenerational Interstellar Exploration with Small Spacecraft

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# Civilizations Studying the Sun, Moon, and Stars

Gaocheng



Image Credit: Gary Todd/ Wikimedia Commons/ public domain [1]

Machu Picchu



Image Credit: Yoann Supertramp/ Wikimedia Commons [2]

Easter Island



Image Credit: Steve Debuizer/ Gemini Observatory

Hovenweep Castle



Images Credit: Troy Cline/ NPS

Karnak



Image Credit: Neithsabes/ Wikimedia Commons [4]

Newgrange



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Ankor Wat

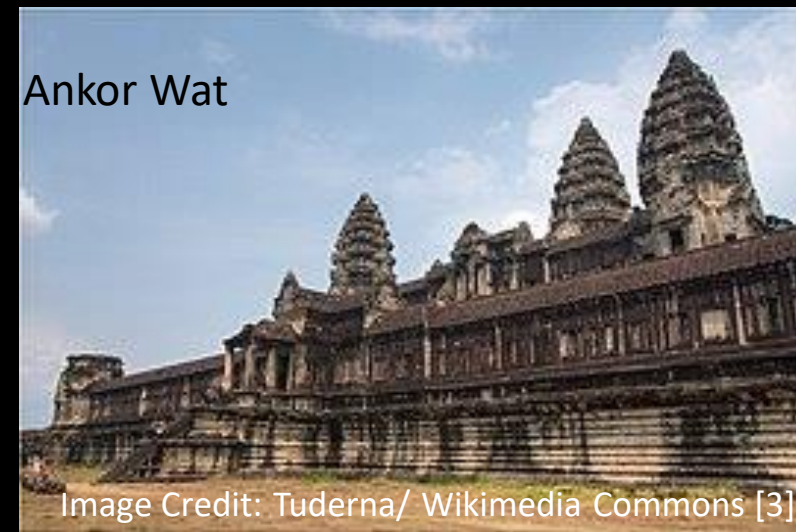


Image Credit: Tuderna/ Wikimedia Commons [3]



# Curiosity and Theism



Image Credit: garethwiscombe/  
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# Philosophy and Astronomy

## *Geocentric to Heliocentric*

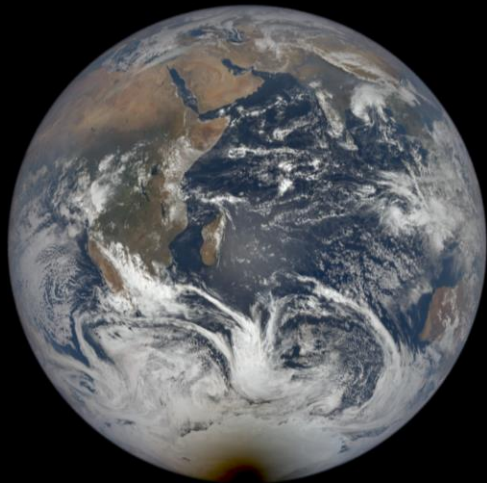


Image Credit: NASA

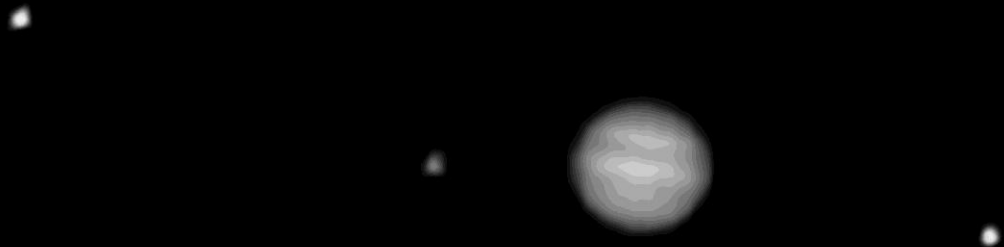


Image Credit: NASA/University of Arizona



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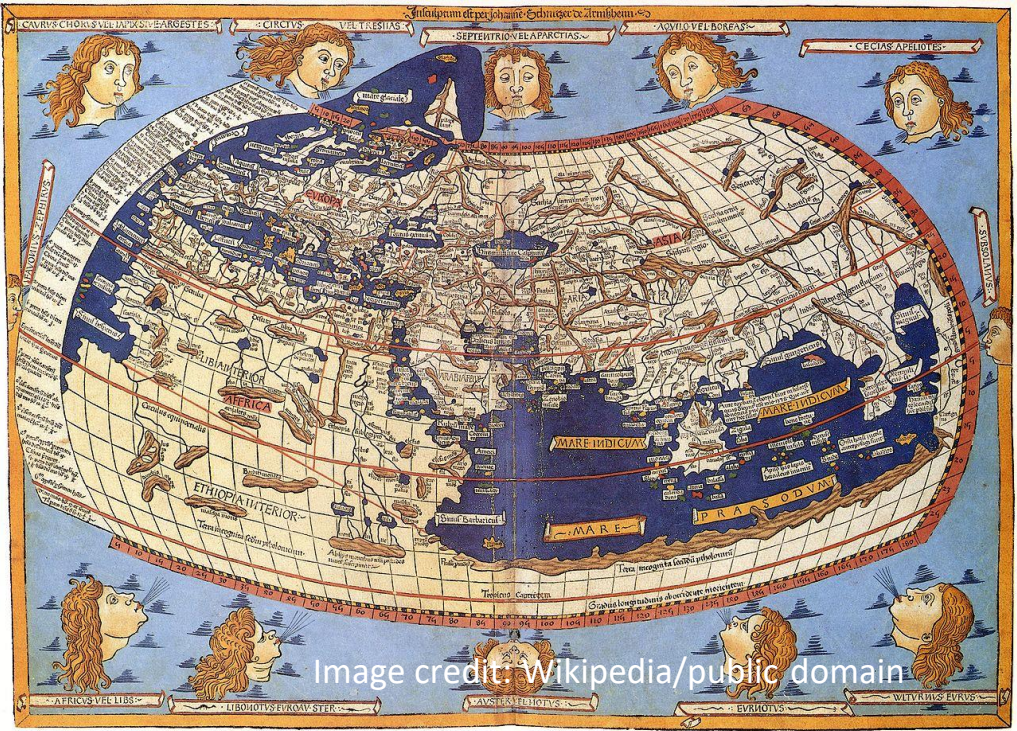


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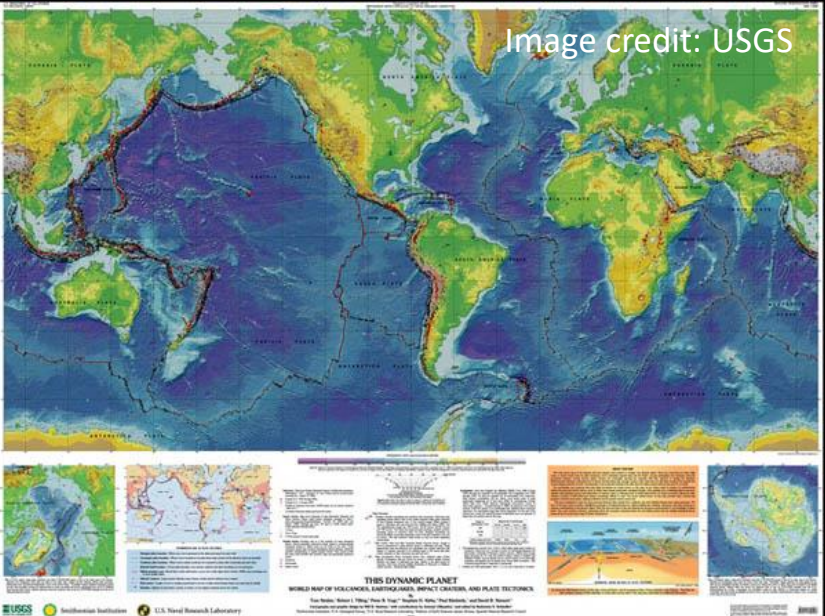


Image credit: USGS

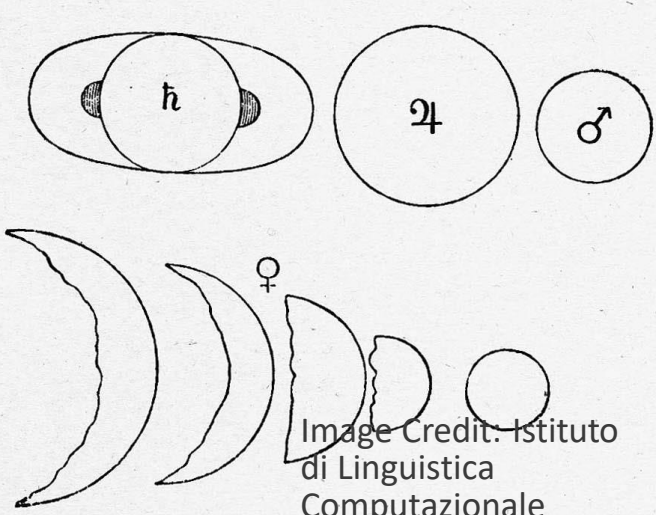


Image Credit: Istituto di Linguistica Computazionale



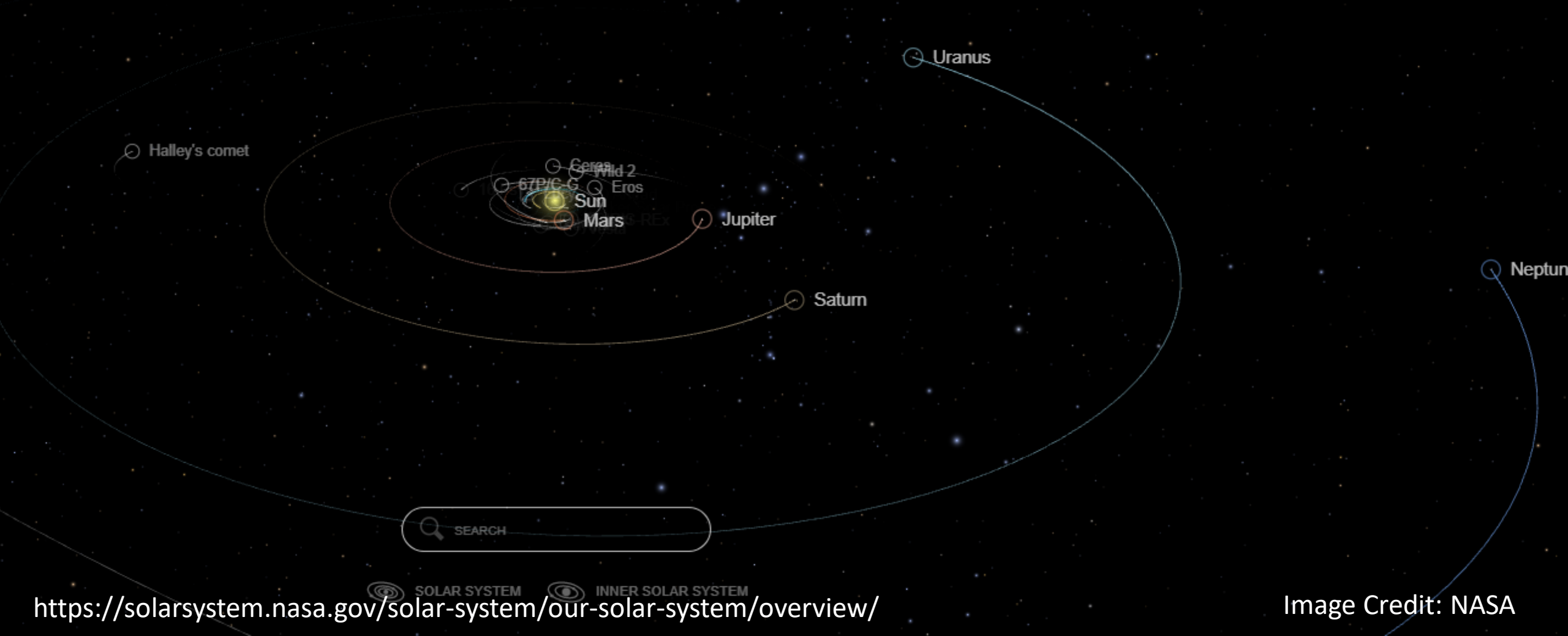
# Exploring First Light with James Webb Telescope

A deep-field astronomical image, likely from the James Webb Space Telescope, showing a bright central star with prominent diffraction spikes. The background is filled with numerous distant galaxies and stars, creating a rich, textured cosmic scene.

<https://www.nasa.gov/press-release/nasa-s-webb-reaches-alignment-milestone-optics-working-successfully>

Image Credit: NASA/STScI

# Exploring the Solar System



# Solar Exploration Missions

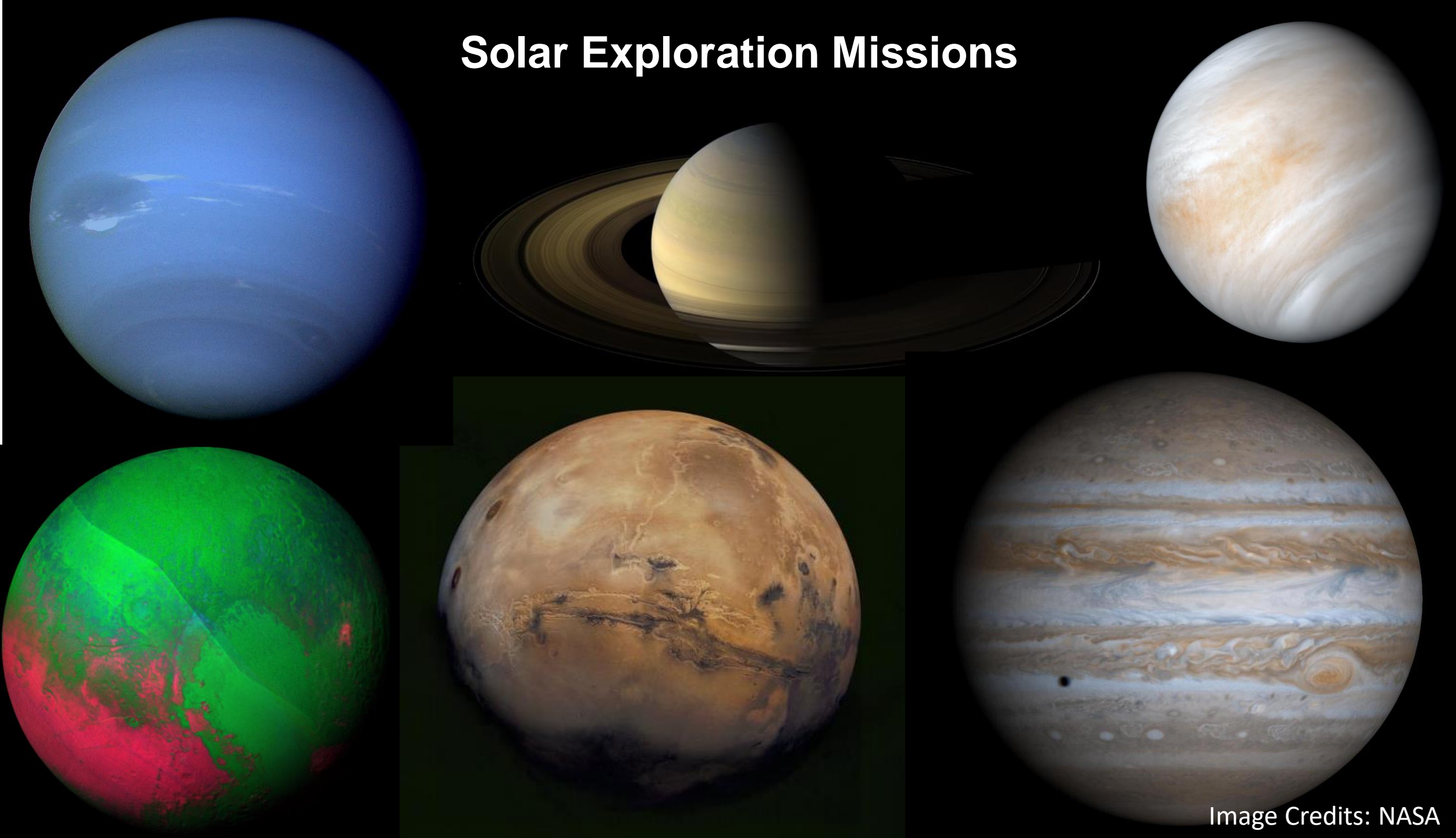
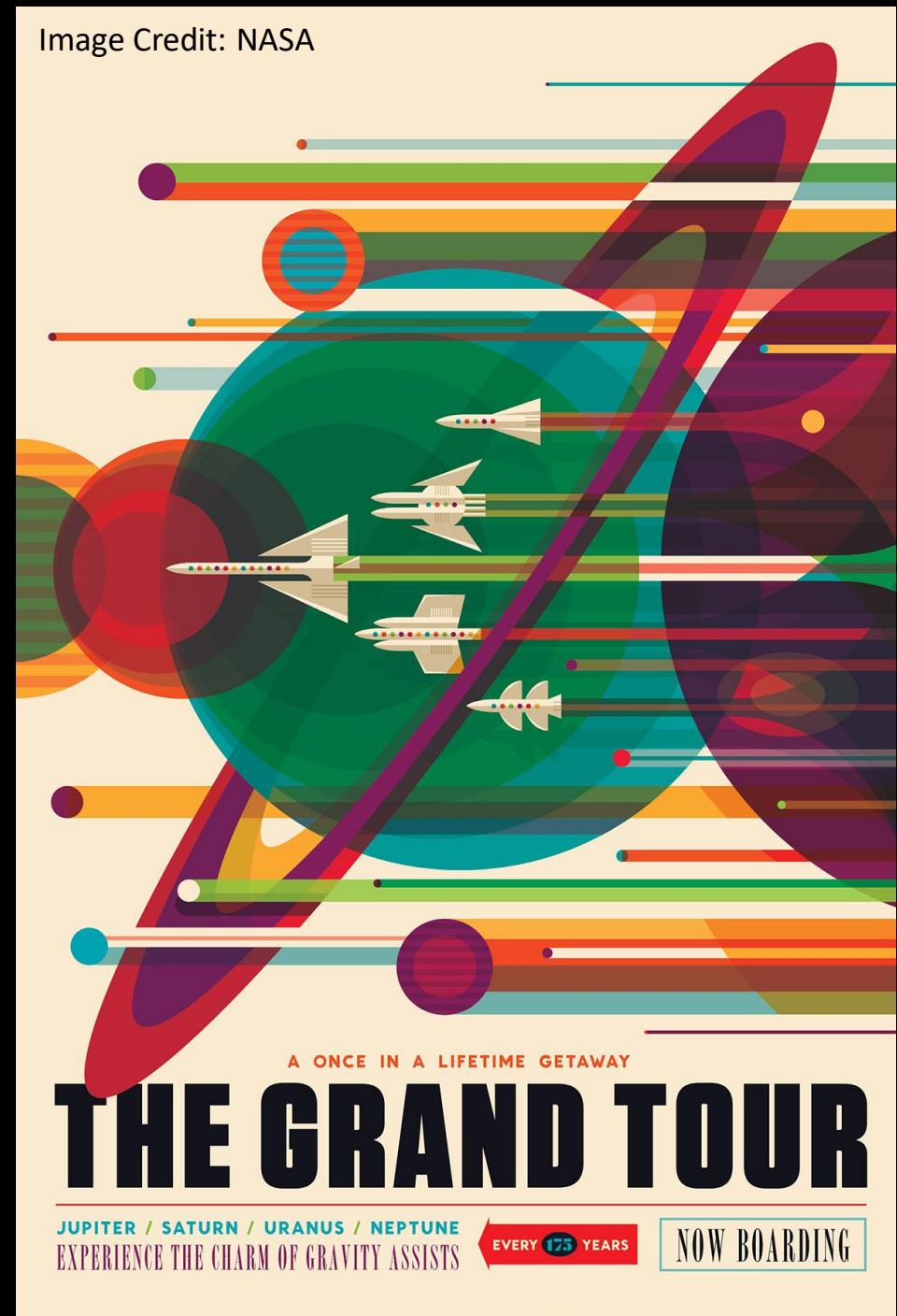


Image Credits: NASA



Image Credit: NASA



# Beyond Solar System: Interstellar

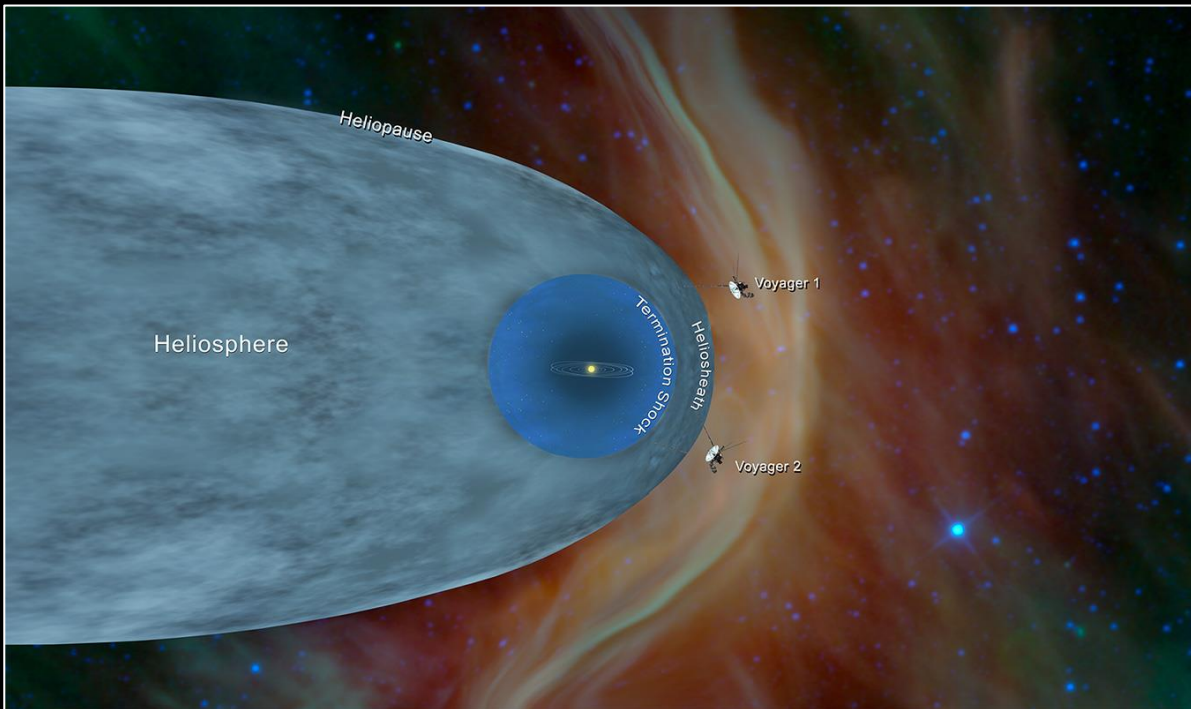


Image Credit: NASA

Mission Elapsed Time 44:06:16:10:52:35  
YRS MOS DAYS HRS MINS SECS

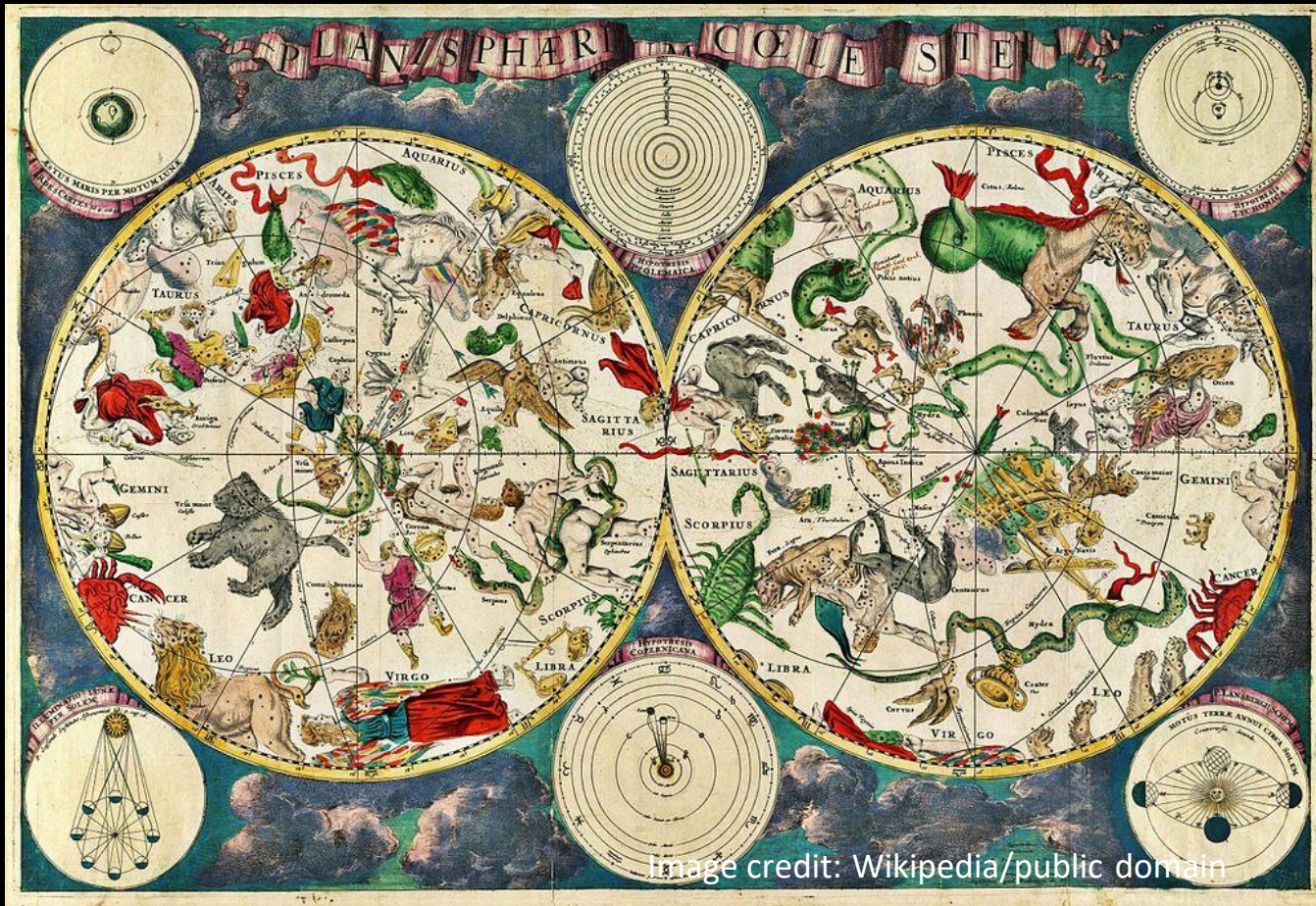


## A large radio telescope dish is positioned on a hillside, with several smaller dishes visible in the background. The sky is filled with stars, and the Milky Way galaxy is prominently displayed, arching across the upper portion of the frame.



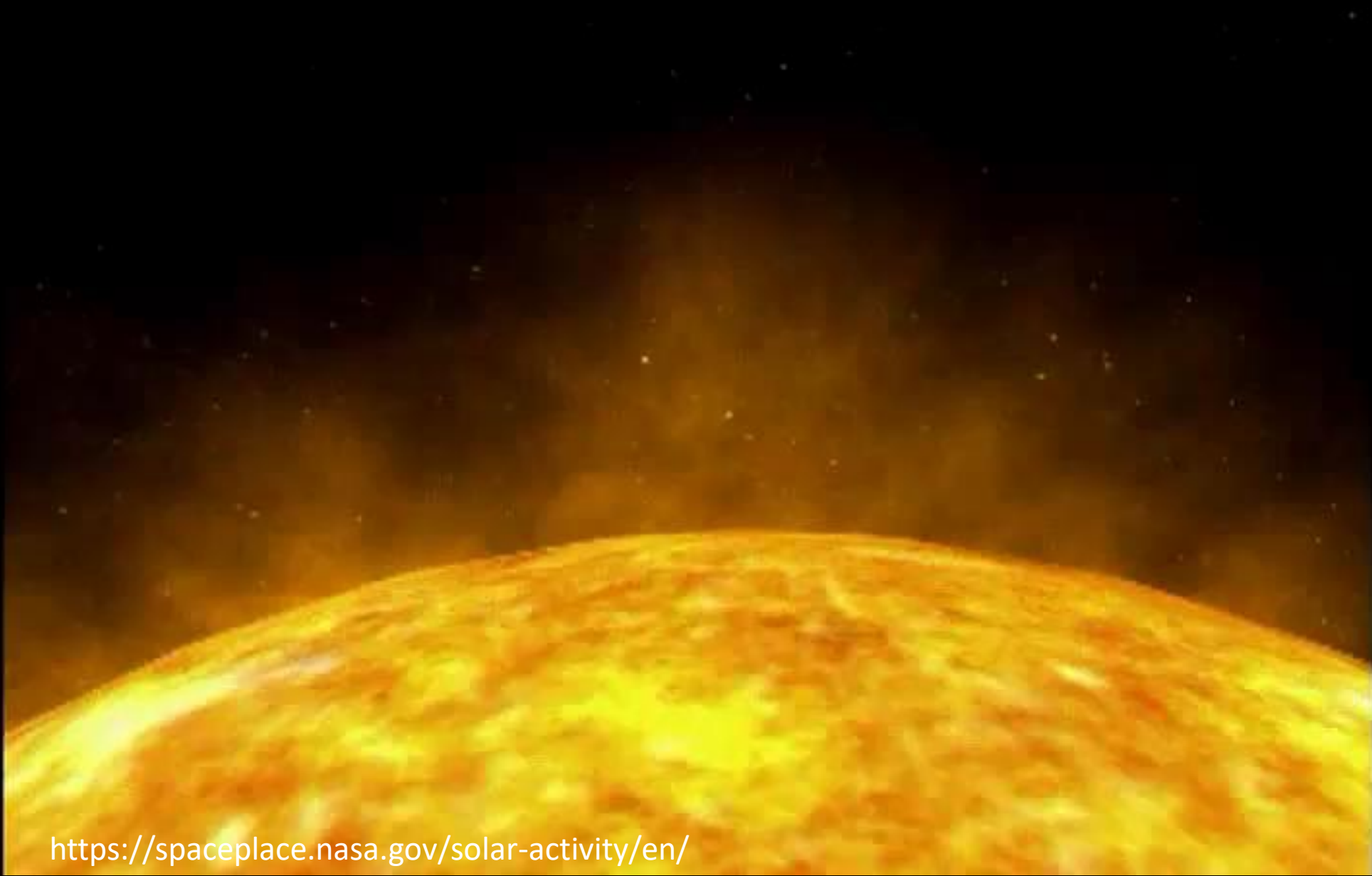


# Our Night Sky Cartographic Improvements





# The Solar Radiation Environment



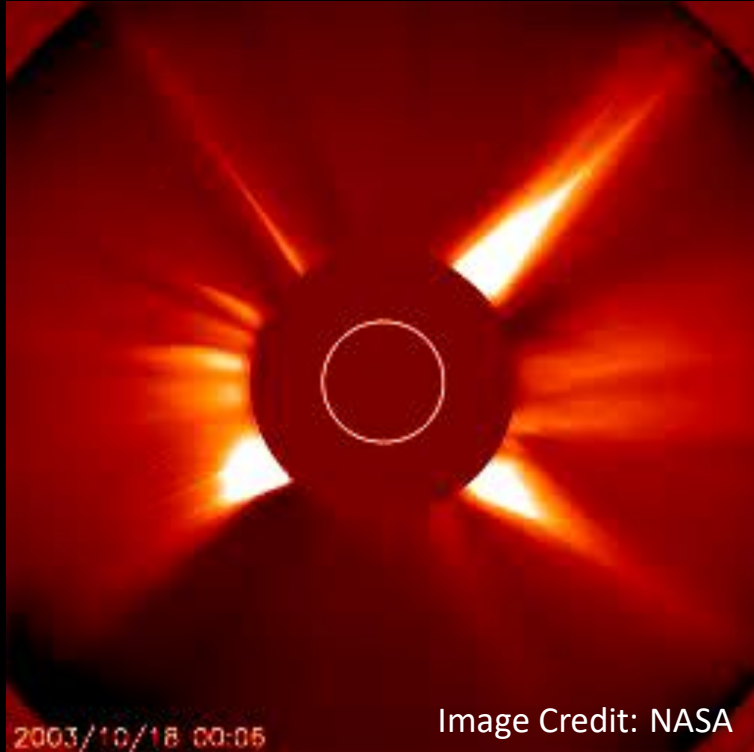
<https://spaceplace.nasa.gov/solar-activity/en/>

Image Credit: NASA

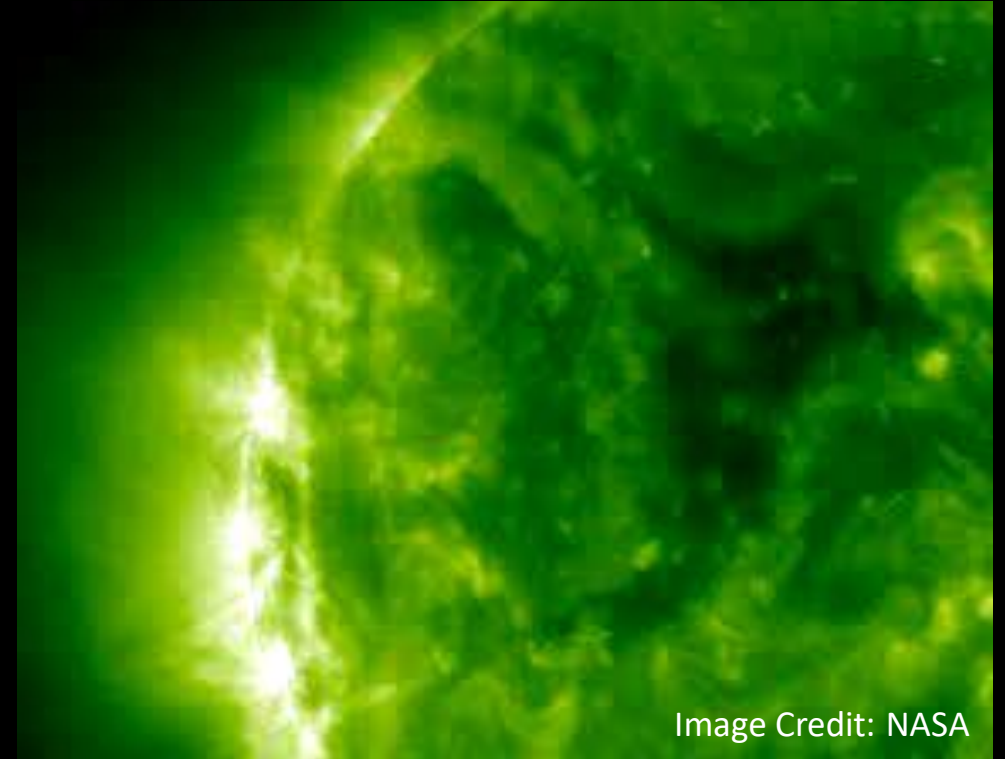


# Solar Flares & Coronal Mass Ejections

*Movies from the SOHO (Solar & Heliospheric Observatory) spacecraft  
“Halloween Storms” – October 2003*

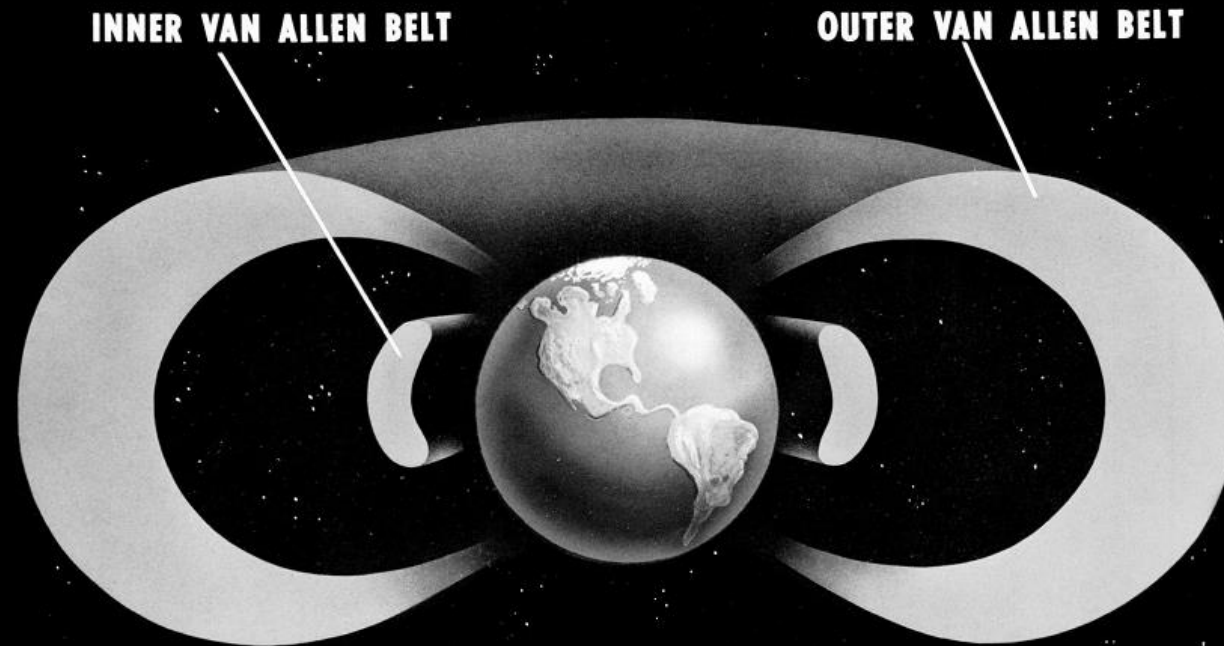


Instrument: Large Angle and  
Spectrometric Coronagraph  
(LASCO)



Instrument: Extreme Ultraviolet  
Imaging Telescope (EIT)

# Van Allen Radiation Belts



S61-479

*NASA's Goddard Space Flight Center/Historic image of Van Allen Belts courtesy of NASA's Langley Research Center*



# Radiation Effects Limit Mission Duration

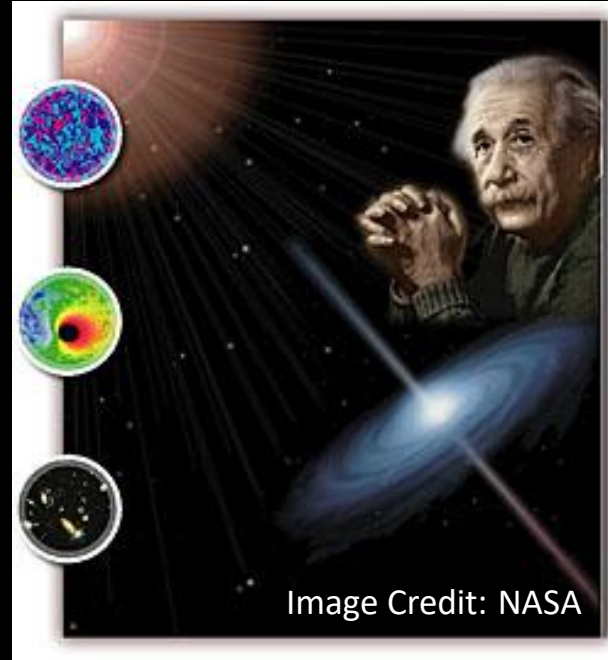
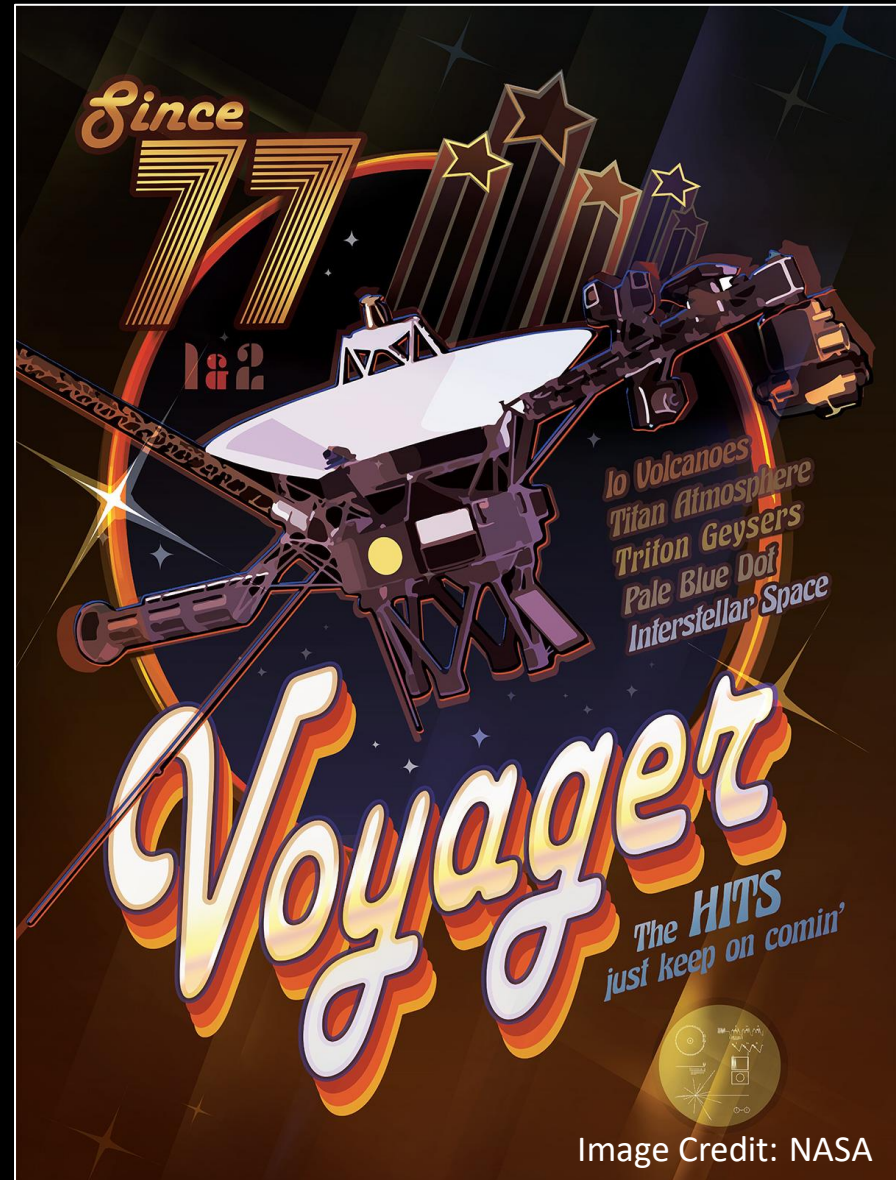
In most cases, amount of shielding reduces the dose rate



*Like a wear rate, a 20,000-mile versus 100,000-mile tire tread life  
If one needs new tires in space, there is no one there to change them, yet.....*

# Slowing Down Radiation Effects like a Time Machine

*Intergenerational: Missions Extending Beyond our Lifetimes*



**NIST** National Institute of  
Standards and Technology  
U.S. Department of Commerce

**THE OFFICIAL U.S. TIME**

Daylight saving time begins on Sunday, March 13th at 2 a.m. (local time) - set clocks **FORWARD** one hour.

**PACIFIC DAYLIGHT TIME**  
PDT (UTC-7)

**12:10:19 P.M.**

**MOUNTAIN DAYLIGHT TIME**  
MDT (UTC-6)

**01:10:19 P.M.**

**CENTRAL DAYLIGHT TIME**  
CDT (UTC-5)

**02:10:19 P.M.**

**EASTERN DAYLIGHT TIME**  
EDT (UTC-4)

**03:10:19 P.M.**

*Disco to Hip Hop Generations*




# Planting the Seeds of Multigenerational Research

- Develop and prepare small spacecrafts that can withstand solar radiation environment, galactic cosmic radiation, and long duration missions
- Nurture academic, government, and citizen interest
- Coordinate multigenerational effort and data availability





# Small Spacecraft Missions: Increasing Complexity and Duration at a Fraction of the Cost of Larger Spacecraft

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Small Spacecraft Technology Program

Earth Science Technology Office

CubeSat Launch Initiative

CubeSats on Exploration Mission-1

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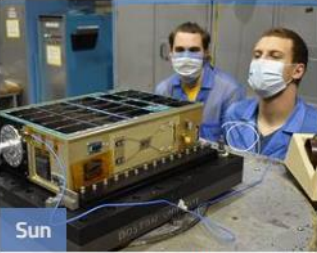
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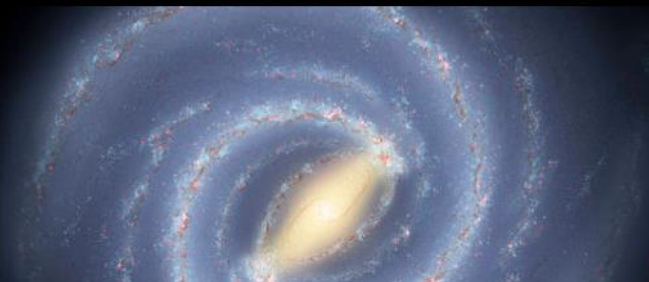
Solar System and Beyond

SIMPLEX Mission Small



NASA Kennedy

ELaNa 31 Mission CubeSats



Solar System and Beyond

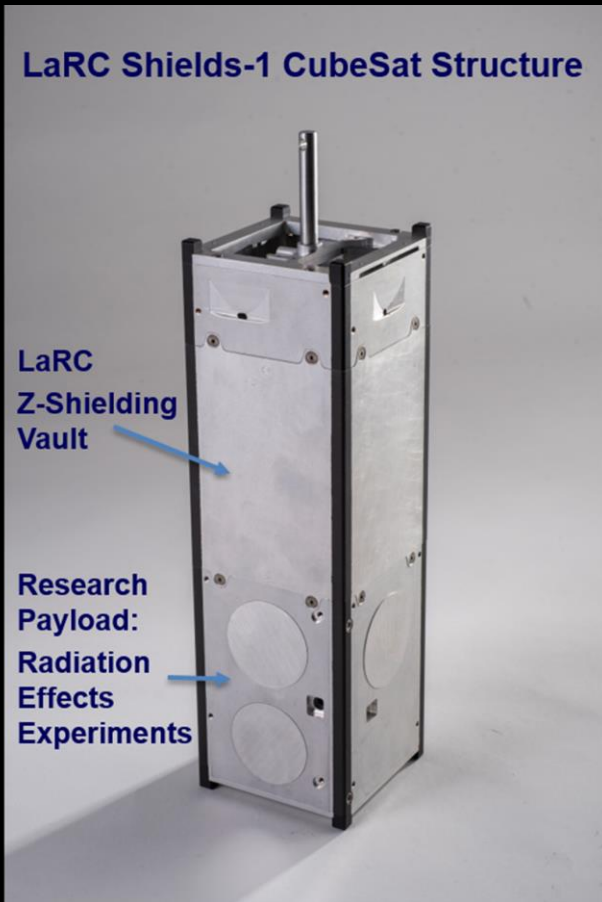
1-cubesats-deployed

Images Credit: NASA



# Shields-1, Space Radiation Effects Experiments NORAD ID 43850

Presently, Shields-1 operates with LaRC Z-Shielding providing radiation protection for the electronics over 3 years in polar low earth orbit



**LaRC Shields-1, Preship for ELaNaXIX Mission, July 2018**



Images Credit: NASA

Shields-1 onboard Rocket Lab USA, Electron Rocket, NASA ELaNaXIX Mission, 16 December 2018 Launch

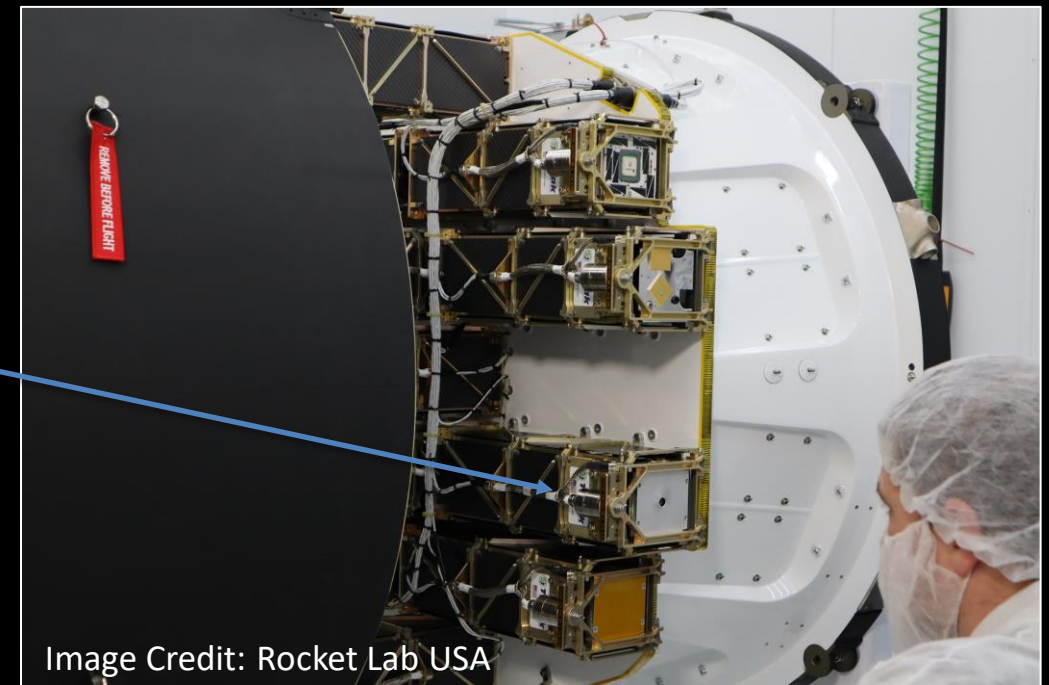
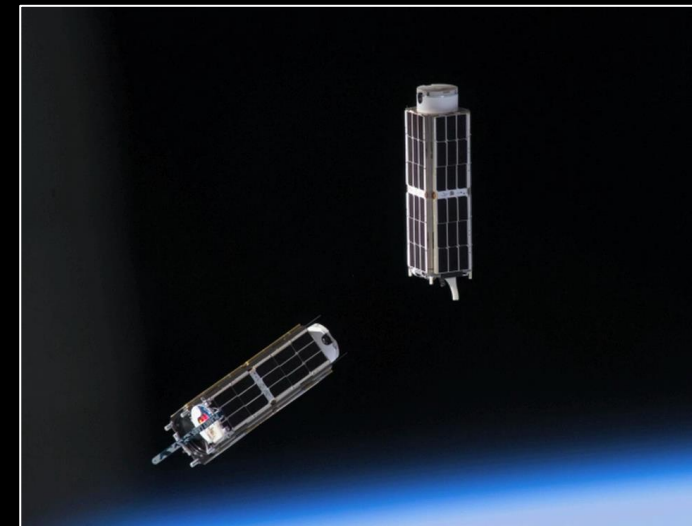
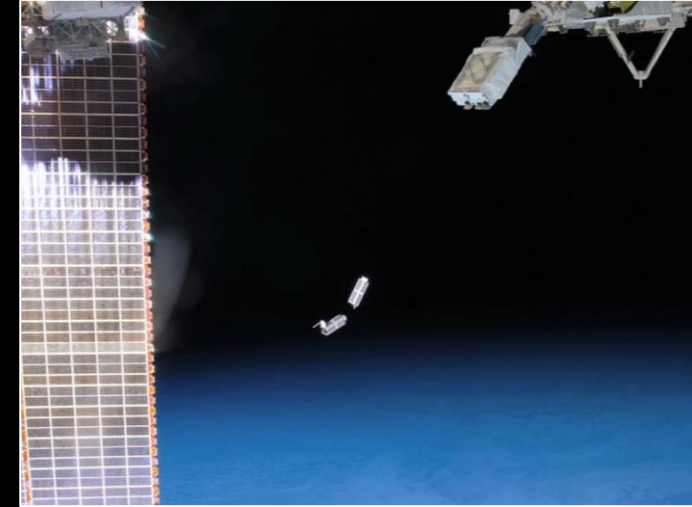


Image Credit: Rocket Lab USA

<https://www.rocketlabusa.com/missions/completed-missions/elana-19/>  
<https://www.youtube.com/watch?v=KZwLJMPuos8>  
<https://www.youtube.com/watch?v=WSCAE-hEa9M>

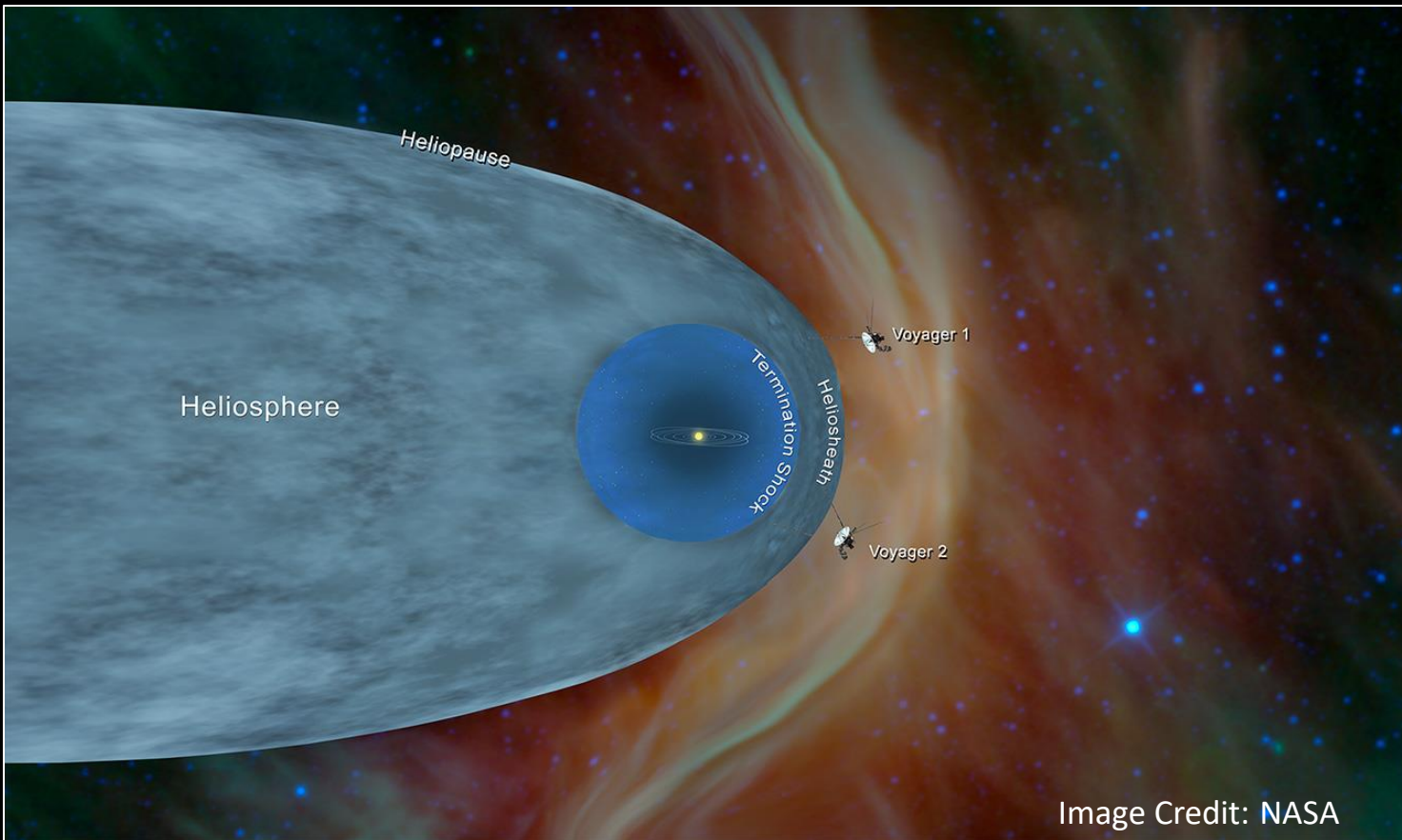
# CubeSat Market: \$0.5B-1B over 3yrs

- Over 1700 small satellites forecasted for 2017-2023 ([www.spaceworksforecast.com](http://www.spaceworksforecast.com))
- Over 500 over next 3 yrs into polar low earth orbit (PLEO) ([www.spaceworksforecast.com](http://www.spaceworksforecast.com))
- Typical CubeSats costs \$1-2M\*  
([https://esto.nasa.gov/techval\\_space.html](https://esto.nasa.gov/techval_space.html))  
*\*NASA ESTO Office reported it is \$1-\$1.5M per U at the 2017 SmallSat Conference and is updating its figure.*
- CubeSat value at risk: \$0.5-1B in the next three years alone





# Voyager 1 and 2: Only Two Trajectories over Our Vast Solar System Boundary and the Rest of the Milky Way



- Artist Depiction of the Heliosphere
- **Voyager 1 and 2 Not to Scale**
- \$865 Million through the Neptune Encounter in 1989
- Typical CubeSat Missions today \$3-6 Million
- Lower launch costs and Spacecraft Weights
- More Capability in a Small Package
- Capability for More Sustainable Missions at a fraction of the Costs of Larger Missions

# Multigenerational Exploration and Modern Civilization History

- **Gifting Forward:**
  - The story of our existence in the Solar System, Milky Way, and Universe
  - Training our next Science, Technology, Engineering, and Mathematics Explorers
- **Engaging our Scientific Curiosity**
- **Adding to Peaceful Cooperation amongst Multiple Cultures and Countries**



Image Credit: [www.nasa.gov](http://www.nasa.gov)



Image Credit: [www.nasa.gov](http://www.nasa.gov)



# References

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# Acknowledgements

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- ELaNaXIX Mission NASA CubeSat Launch Initiative
- NASA Wallops Flight Facility CubeSat Ground Operations